NEW STRATEGIES FOR ENVIRONMENTAL MANAGEMENT IN HARBOURS: THE CASE OF THE TARRAGONA PORT MONOBUOY

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Abstract:

Ports are a potential focus of sea pollution and therefore port authorities and operators have a key role on the sustainability and environmental protection of the coastal waters. In the last decades, monitoring techniques of the marine environment have been implemented in ports, and accurate meteo-oceanographic prediction systems have been developed. New available systems may be used to obtain real-time data in order to improve risk assessment and the management of pollution events (e.g. video surveillance systems, Unmanned Aerial Vehicles (UAV), remote sensing products, etc.). The availability of meteo-oceanographic operational services (for instance, the SAMOA initiative from the Spanish Port Agency) allows to implement statistical techniques, such as Monte Carlo simulations, to perform probabilistic studies of potential pollution events. This contribution aims to develop new strategies, focusing on two aspects of the marine management: 1) The incorporation of the statistical methods and the available data of the physical environment; and 2) The design of environmental risk management strategies adapted to the present regulations. These tools may enhance efficiency in the environmental management of port waters and nearby coastal areas reducing the negative impact of pollutant discharges.

Keywords:

Environmental risk assessment; oil spills; SAMOA project; Medslik model; Monte Carlo method.

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INTRODUCTION

The environmental pollution caused by port operational accidents has received an increasing attention in the last decades associated to the increased environmental sensibility and blue growth. In particular, pollution by hydrocarbons is relevant because of its frequency (they are present in approximately 57% of accidents involving chemical substances [1]) and their toxicity. The oil pollution of marine habitats is an issue not only for researchers and environmentalists, but is also a main social and political concern, due to the serious impact of oil spills on marine life and on human activity, tourism and the exploitation of the sea's resources.

Both public port administration and the private operators of ports and terminals have therefore to consider the potential effects of their activities on the marine environment in their planning and management. So, port managers need tools in which the interactions of logistic and environmental factors can be considered to define their policies. Thus, environmental risk assessment tools are meant to become a generalized tool for environmental management and decision-making for port authorities [2]. This management relies on the three-step process of hazard identification, risk assessment and risk management. Environmental risk assessment requires a description of hazards, the determination of the probability of impact, the vulnerability of the environment and thus derives the consequences from a hazard. This contribution focuses on the determination of the probability of impact.

Oil spill hazard can be considered under the source-pathway-receptor-consequence (S-P-R-C) methodology [3]. A critical point in this methodology is the analysis of the potential pathway between source and receptor. The hydrodynamic information of the receptor domain is necessary to analyse the pathway [4]. In recent years, several types of risk management instruments have been postulated in order to mitigate the potential environmental hazard in port operation. Two main classifications of such instruments can be considered [5]. First classification, according to their analytical approach, results into nine groups: even tree analysis, failure mode and effects analysis, fault tree analysis, risk maps, scenario analysis, bayesian belief networks, decision tree, bow-tie analysis and cause-consequence analysis. Also, the instruments can be classified according to the support method into four groups: analytical hierarchy process, fuzzy theory, evidential reasoning and simulation methods. Our work is directed to the risk map approach supported by simulation methods. Several examples of such instruments can be found [6, 7, 8, 9, 10, 11 & 12].

In this paper, we investigate the spatial distribution of probability of impact of an oil spill in the dock or the monobuoy of the port of Tarragona using a Monte Carlo method. We take advantage of the operational information available to use real wind and water current conditions for the oil spill simulations. Our goal is to verify the validity of the new method and the reliability of the results obtained.

The study case is the port of Tarragona, located on the Mediterranean coast of Spain (approximate coordinates are 1°14′E 41°05′N), which accommodates a hub of petrochemical industry. Wind and water current data in the port area are obtained from the SAMOA system (Sistema de Apoyo Meteorológico y Oceanográfico de la Autoridad Portuaria). SAMOA is an initiative of the Spanish Public State Port Agency to provide Port Authorities with user-customised operational met-ocean information for harbour safety, environmental management and operational decisions [13].

The paper is organized as follows. Section 2 describes the site and introduces the risk management instrument as well as the operational data and the model used. Section 3 presents the results of the simulations and a discussion on the design criteria for the risk management instrument.

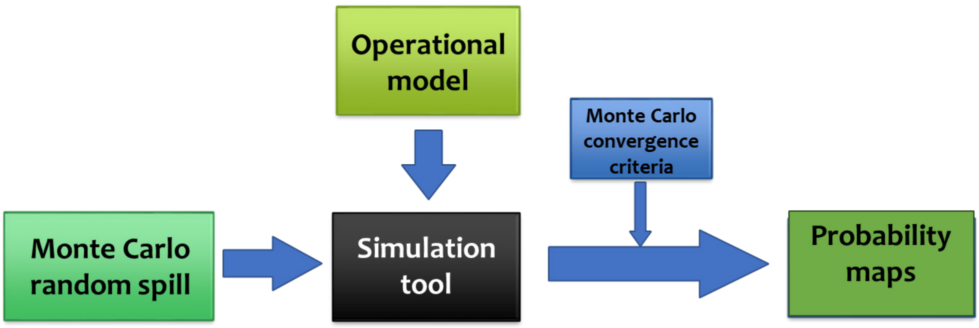
1. MATERIAL & METHODS

The port of Tarragona is the main petrochemical port in the Mediterranean coast of Spain, connected to one of the largest Spanish oil refineries, and also an important industrial and commercial harbour. Repsol Petróleo, SA, owner of the oil refinery, operates a liquid bulk terminal within the port with mooring capacity for five vessels and an offshore station (i.e. monobuoy) for the mooring and unloading of very large vessels.

This port is very suitable for the implementation of new strategies for two reasons: the availability of detailed meteo-oceanographic operational data, and the existence of previous studies on oil spill environmental risk for comparison [6, 7, 8, 14 & 15]. In this sense, we define different environmental risk management tools which can be described using a conceptual layout (see Figure 1) with a set of inputs and outputs focused on environmental management.

This work is particularized for a tool with a specific layout (see Figure 1) whose purpose is to create probability maps associated to accidental spills in the oil transfer facilities of the harbour. The layout centres on the application of the simulation tool and the operational meteo-oceanographic models and the interpretation criteria for the results obtained from the simulation.

Figure 1. Layout of the environmental management tool for accidental spills in the oil transfer facilities of the port of Tarragona.



This tool is based on a set of Monte Carlo iterations using oil spill simulations obtained from an upgraded version of MEDSLIK-II, a Lagrangian model that simulates the evolution of a discharge of hydrocarbon products in the sea considering the effects of transport, dispersion and weathering, as well as the eventual oil fixation at the coast [16 & 17].

The model has been used to provide the position of oil particles at different time steps during a set of different simulated scenarios. By directly combining the results of all the simulations, the probability of oil presence has been obtained in terms of the superposition of the particles' positions.

The premises considered in the Maritime Interior Plan of the Repsol installation of the port of Tarragona (written in 2009) have been used to parametrize the oil spill. A discharge of 5.4 T of crude oil has been considered in the simulations. An instantaneous spill has been defined since the duration suggested by the plan (i.e. 5 minutes) is negligible in comparison to the simulation period. This hypothesis does not significantly alter the probability maps obtained.

The model was forced by wind and hydrodynamic fields obtained from the SAMOA project. Specifically, data corresponding to the period between October 2017 and September 2018 have been used, providing one year of data and allowing to perform simulations evenly distributed along all months. These have been designed using a Monte Carlo algorithm to define a random release time for the simulated oil spills. Thus, combinations of different releases, with the associated meteo-oceanographic conditions given by SAMOA, are generated randomly. The evolution of the oil slick has been obtained using MEDSLIK-II.

Numerical experiments have been carried out with oil spills from the monobuoy and from the dock. The simulation length is 8 hours, with a 6-minute timestep, and model results were recorded for each time step. The number of tracer particles used per simulation was 10. The value adopted for horizontal diffusivity for both spill cases (10 m^2/s) has been chosen after a sensitivity analysis within the limits suggested in the literature [18].

The results obtained in the experiments have been used to generate first impact probability maps based on particle counting within predefined cells. Each probability map has been obtained by normalizing the corresponding particle count map, i.e. dividing the value in each integration cell by the maximum value, which corresponds to the cell where the spill originates.

2. RESULTS AND DISCUSSION

Probability maps obtained are presented in Figure 2 for oil spills occurred in the dock and in Figure 3 for oil spills from the monobuoy. These maps take into consideration the probability of presence of tracer particles at a given point at any time during the 8-hour simulation period. Probability is computed only in the area where convergence of the Monte Carlo series has been achieved. For visualization purposes a logarithmic probability scale has been chosen.

Figure 2. Probability map for spills from the dock.

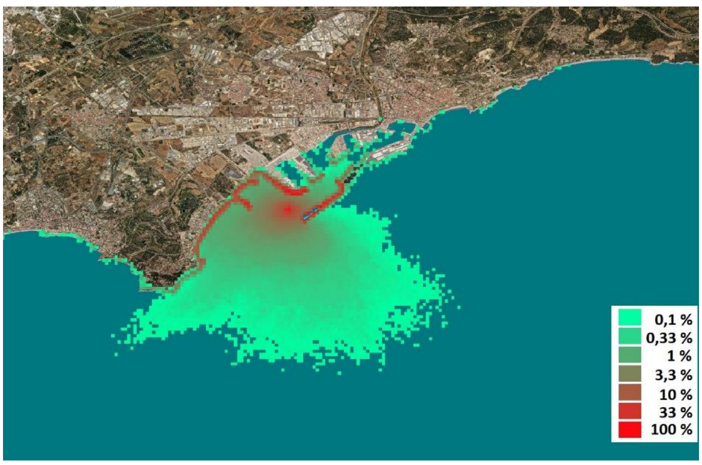
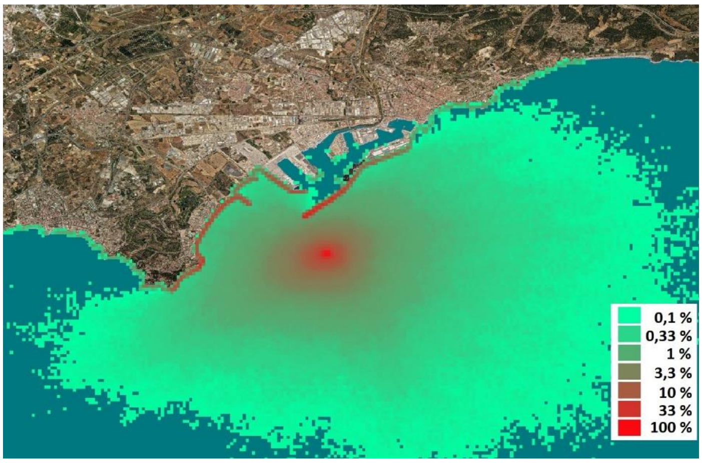


Figure 3. Probability map for spills from the monobuoy.



The comparison of these probability maps (i.e. Figure 2 and 3) suggests that a spill from the monobuoy can potentially affect a larger area than an oil spill occurred at the dock. These probability of impact results are consistent with the results of previous studies which highlight the protection provided by Cape Salou [14 & 14] (shown in figure 4). Furthermore, they area also compatible with the studies suggesting three main directions of oil dispersion (approximately E, ESE & WSW) for the monobuoy spill [6, 7 & 8] (shown in figure 5) as a result of the typical meteo-oceanographic patterns.

Figure 4. Effect of Cape Salou: (a) dock spill, (b) monobuoy spill. Yellow arrows show the main direction of dispersion of a potential oil spill based on probability maps.

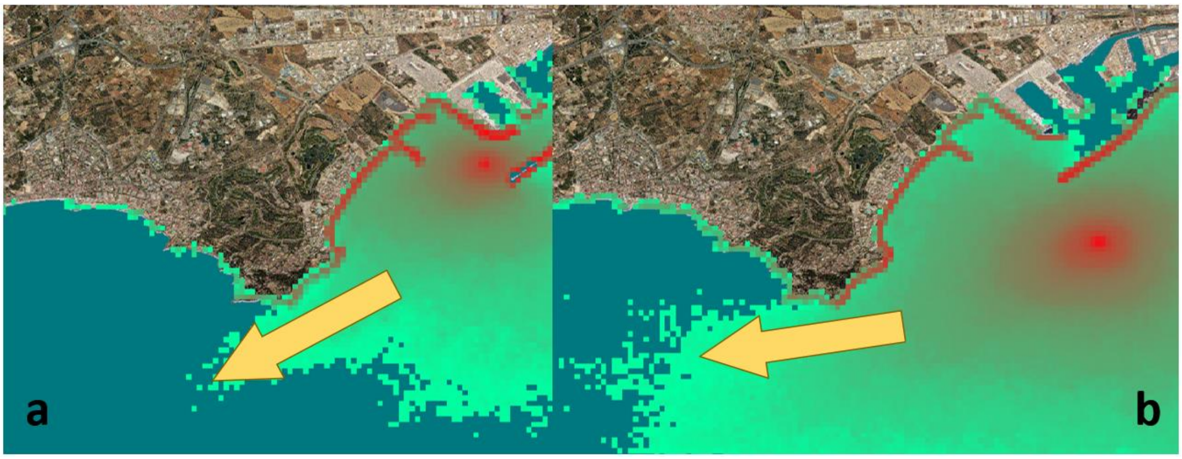
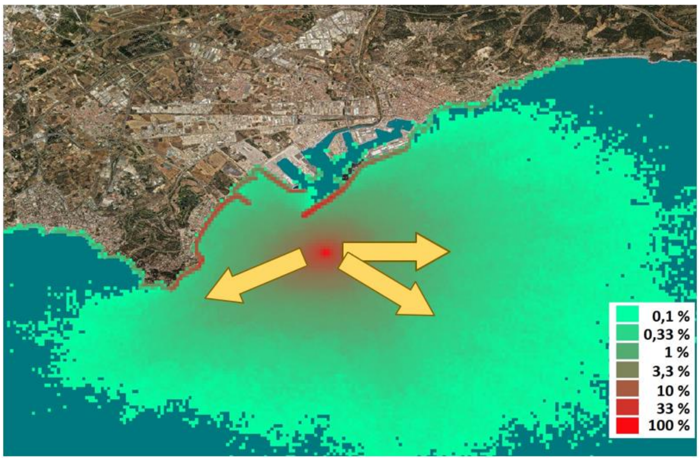


Figure 5. Main directions for oil spills from the monobuoy. Yellow arrows show the main direction of dispersion of a potential oil spill based on probability maps.



The impact probability maps obtained, presenting the three main directions shown in figure 5, are consistent with the meteo-oceanographic characteristics of the region [19, 20, 21, 22 & 23] that are: *a)* south-westwards averaged water circulation and *b)* NW energetic wind events.

3. CONCLUSIONS

The probabilistic method presented, based on Monte Carlo simulations, allows us to obtain impact probability maps using information from meteo-oceanographic operational systems. The results shown for oil spill risk in Tarragona Port facilities, validated with previous studies for those facilities and consistent with the meteo-oceanographic characteristics of the region, suggest that this tool is appropriate for environmental management systems in other ports where meteo-oceanographic operational systems are available. Also, this method's potential will grow with the development of meteo-oceanographic operational systems models in ports and coastal areas and the accumulation of data. In the implementation of this method, the scope and scale of the maps have to be considered taking into account the available meteo-oceanographic information and the model requirements. In areas with limited meteo-oceanographic information, expert judgment will be necessary if areas with low probability of impact have to be considered.

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